



349-nm Source for Direct Detection Measurement of Winds

Yelena Isyanova and Peter Moulton

*Q-Peak Inc. Q-Peak, Inc.,
135 South Rd.,
Bedford, MA 01730*



What is Q-Peak's technology base?

- **Solid state lasers**
 - Lamp and diode-pumped
 - Wide variety of laser materials
 - Wavelengths from 700 to 2800 nm (for now)
 - Formats include CW, Q-switched, single-frequency, mode-locked, broadly tunable
 - Specialty is cw-pumped, high-beam quality devices
- **Nonlinear optics**
 - Driven by solid state lasers to shift wavelengths up and down
 - Harmonic generation to shorter wavelengths (700-195 nm)
 - Optical parametric oscillators for longer wavelengths (1200-12000 nm) and for tunability
- **Skills used to advance technology**
 - Optical and laser engineering, materials science, electronic, thermal and mechanical engineering
 - In some cases on the boundary of science and engineering



Sensor Description (from estips.gsfc.nasa.gov)

The Direct Detection Doppler Wind Lidar option measures tropospheric winds by illuminating the atmosphere with a laser signal and detecting returns from molecules and aerosols. The Doppler-shifted returns are sent through an high-resolution optical filter whose transmission is wavelength dependent. Intensity differences indicate frequency shifts related to wind velocity. This technique offers coverage over the full tropospheric altitude range, i.e., 0-20 km. Molecular returns will be best in the upper troposphere above 3 km and aerosol returns best below 3 km. The direct detection technique offers tolerance to optical alignment errors, relative insensitivity to imperfect optics, and more technologically developed and space-qualified laser transmitters.



Solid State Laser Performance Requirements

	NOMINAL	Q-Peak
Wavelength	345- 355 nm	349 nm
Beam quality	TEM ₀₀	Same
Longitudinal mode	Single longitudinal mode; Single frequency	Same
Spectral linewidth	< 200 MHz @ 349 nm	Same
Frequency stability	<5 MHz over 30 seconds	TBD
Pulse length	> 10 ns	Same
Average power	> 2.5 W	4 W
Pulse repetition rate	2 kHz	1 kHz



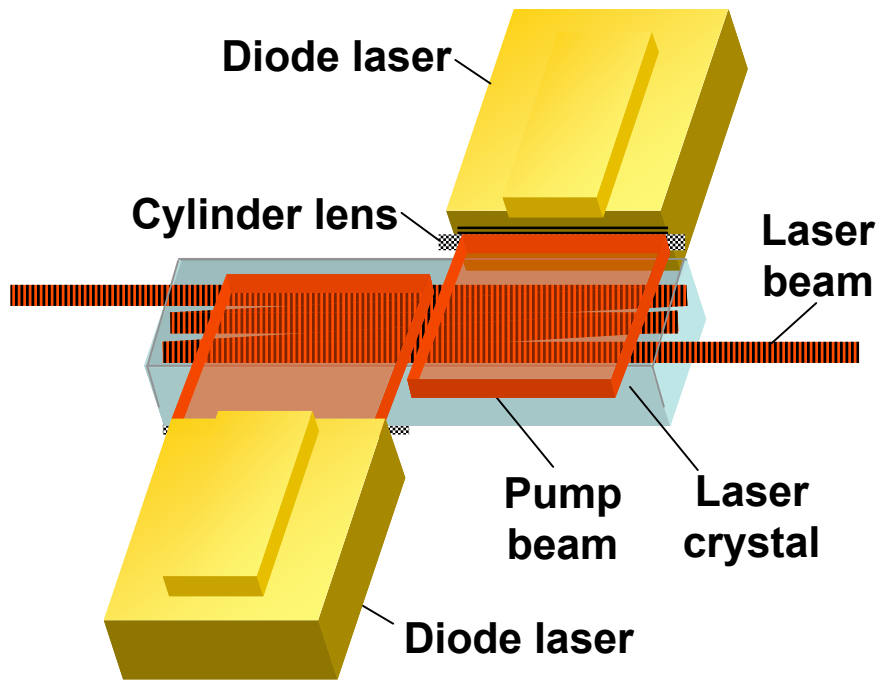
Q-Peak Approaches to meet laser requirements

Wavelength	Use of nonlinear crystals for consecutive doubling and tripling of 1047-nm laser beam
Beam quality	Ring resonator designed to support only fundamental laser mode
Single frequency	Injection seeding using single-frequency seed laser and pulse-build-up-time reduction technique
Spectral linewidth	Defined by pulse width and frequency stability
<i>Frequency stability</i>	<i>Design ruggedization;</i>
Pulse length	Electro-optic Q-switching of high-gain laser
Average power	Use of Nd:YLF, high-energy-storage laser material; Side-pumped Multipass Slab design; Maser-oscillator Power-amplifier configuration
Pulse repetition rate	CW, conductively cooled pump laser diodes

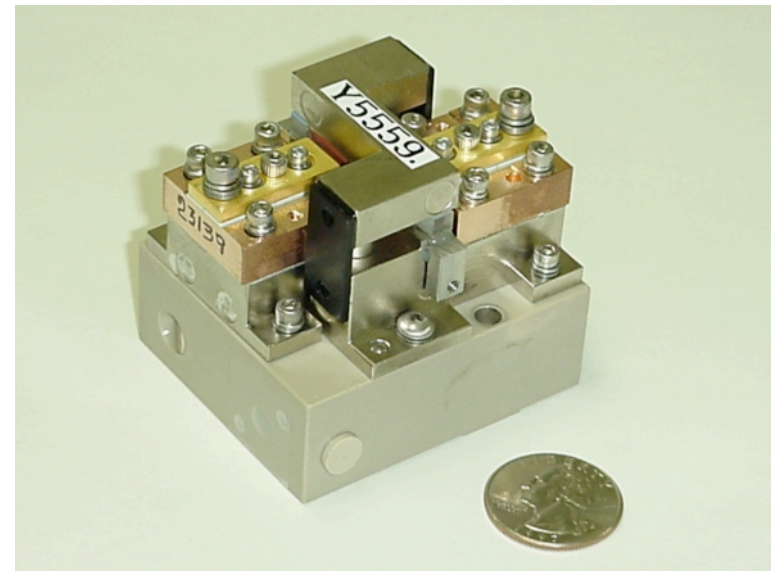
Areas of challenge: Frequency stability, and in the long-term, scaling to the Joule-level energies need for space-based systems



**MPS Nd:YLF laser design obtains high efficiency
and high beam quality with side-pumping**



**Multi-Pass Slab (MPS)
US Patent 5,774,489
40% optical-optical efficiency**



“Gain Module”

Why Nd:YLF as the laser material?

- **Nd:YLF is naturally birefringent and thus does not exhibit the stress-induced birefringence of Nd:YAG at high pump powers. This allows generation of linearly polarized light without pump-induced losses in the laser material.**
- **The upper-state, or storage, lifetime of Nd:YLF is twice that of Nd:YAG. For a given diode pump source, this allows the generation of twice the energy under pulsed conditions, or a halving of the number of diodes required to produce a given energy.**
- **Nd:YLF has significantly lower thermal lensing compared to Nd:YAG and other oxide host crystals. This simplifies laser designs in which high beam quality is desired and reduces changes in beam properties (size and pointing) with changes in pump power.**
- **Q-Peak has many years of experience with Nd:YLF and has engineered reliable, lamp-pumped Nd:YLF lasers generating 1 J/pulse at 10 Hz and diode-pumped systems producing 85 W of average power. Q-Peak has built over 200 MPS Nd:YLF modules.**

Nd:YAG and Nd:YLF comparison

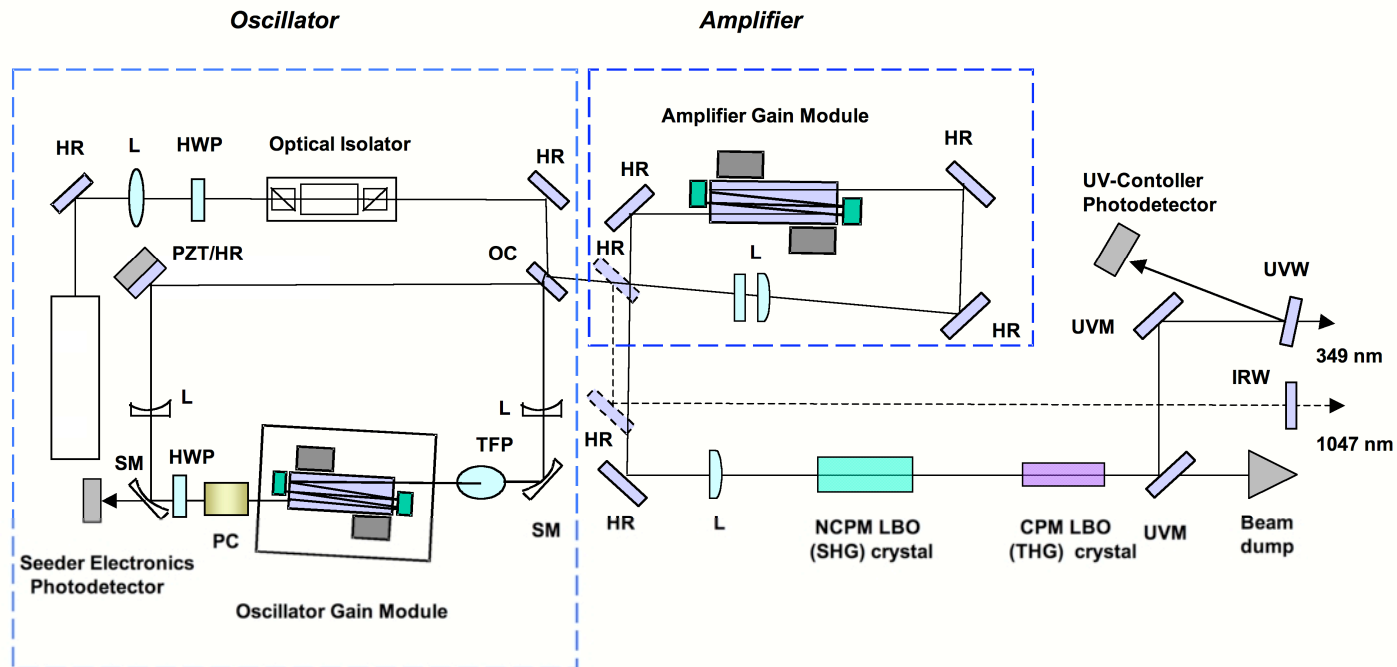
Properties of Nd:YAG and Nd:YLF laser parameters

	Nd:YAG	Nd:YLF
Emission wavelength, nm	1064	1047 (1053)
Emission cross-section, cm ²	8.8×10^{-19}	$1.8 \cdot 10^{-19}$ (1047 nm) $1.2 \cdot 10^{-19}$ (1053 nm)
Fluorescence lifetime, us	230	485
Thermal conductivity, W/m·K	13	6.3
dn/dT	$7.3 \times 10^{-6} / ^\circ\text{C}$	$-4.3 \times 10^{-6} / ^\circ\text{C}$ (E c) $-2.0 \times 10^{-6} / ^\circ\text{C}$ (E \perp c)



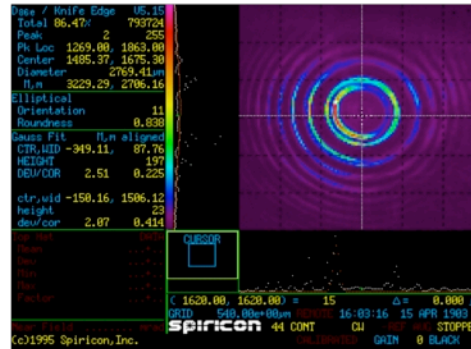
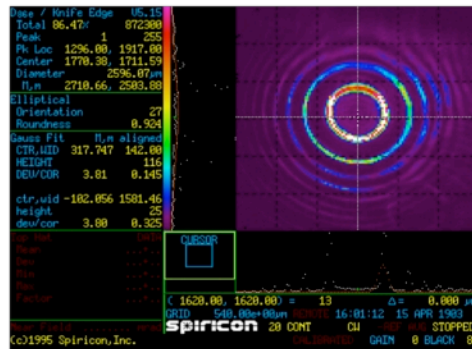
Q-Peak developed a MPS-based, single-frequency UV transmitter under NASA Phase II SBIR funding

Optical schematic



Phase II (NAS5-02016) laboratory UV Transmitter, delivered to NASA Goddard in July 2004, generated 4-W average power at a 1-kHz pulse rate

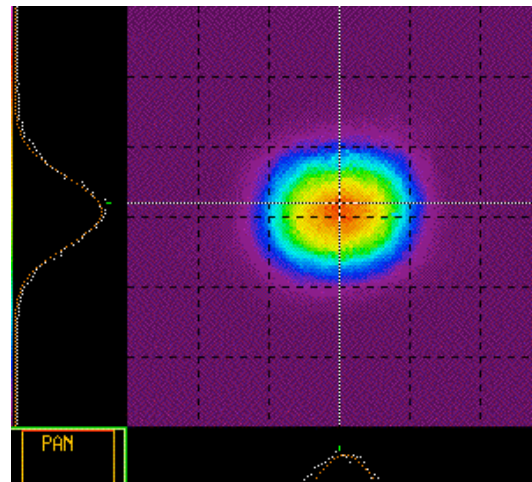
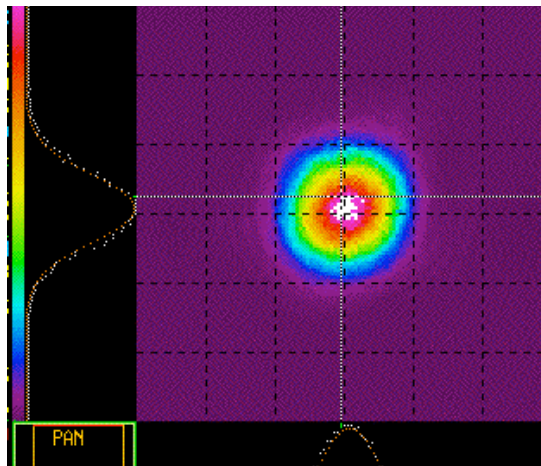
Phase II Transmitter: Single-frequency, TEM₀₀ operation



Interferograms and beam profiles
of Q-switched pulses
(a) with seeder electronics on
(b) with no injection locking.

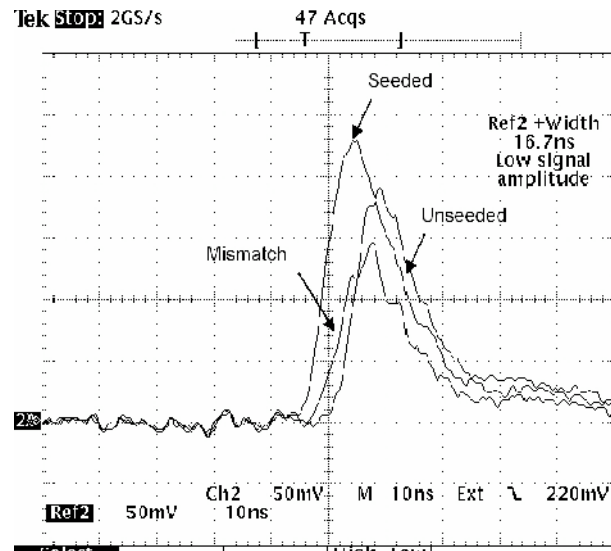
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To resolve the adjacent longitudinal modes of the ring resonator, we set the space between the interferometer mirrors at 12.4 cm so the FSR was equal to 0.0403 cm^{-1} or $\sim 1.2 \text{ GHz}$. The optical length of the ring resonator was equal 73 cm thus providing the spacing between adjacent longitudinal modes of 0.0136 cm^{-1} or 0.4 GHz. Thus, with this setting, at least 3 adjacent longitudinal modes could be resolved.

Oscilloscope traces of ring-cavity pulses in different modes of operation



Seeded - perfect resonance

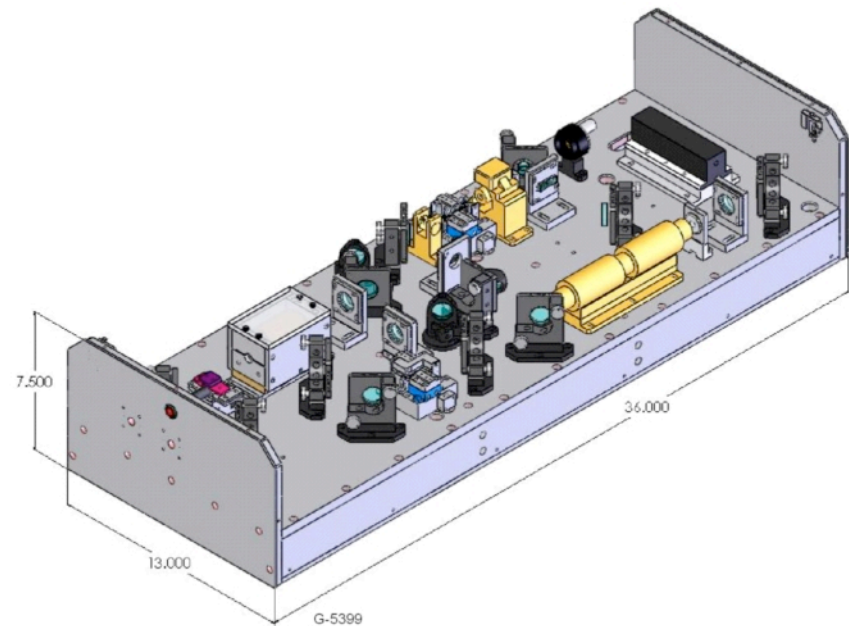
Mismatch - not perfect resonance

Unseeded - no seed laser beam

Maximum energy per pulse achieved in the injection-locked mode was 5.8 mJ scaled up to 16.1 mJ using a single-stage amplifier.



Phase II UV Transmitter: Photo of power supply and CAD drawing of laser head





NASA SBIR Phase III (under negotiation): Objectives

- (1) Characterization of the frequency stability of the 1047 -nm seed lasers and study of ways to improve stability to meet the requirements for Doppler lidars. Work on this objective will include search and analysis of stability characteristics of existing seed laser sources including a GTL laser from AdVR Inc.**
- (2) Comparative analysis of the frequency stability provided by different seeding techniques. Given that the frequency stability of the seed laser is satisfactory, we will investigate that of the PBTUR -injection-seeded oscillator. Other approaches, such as the ramp and fire approach or the Pound-Drever-Hall method will be studied.**
- (3) Deliver the packaged, turnkey system to NASA GSFC including the laser head, power supply and chiller unit. Our goals:**

Wavelength: 349 nm

Pulse energy: 4 mJ

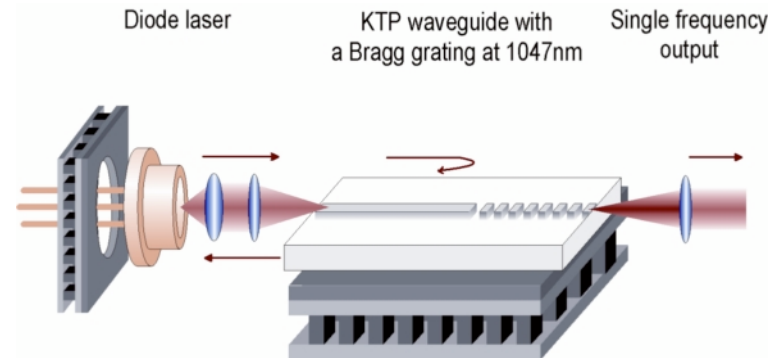
Pulse rate: 1 -2 kHz

Short term drift = < ± 1 MHz over 30 s

Long term drift = < ± 200 MHz



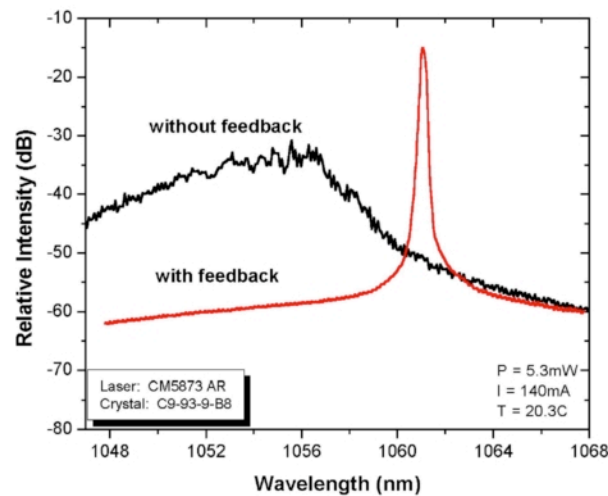
AdvR, Inc. seed laser is an important sub-component



Wavelength = 1047nm

Power = 5-10mW

Frequency Stability < 100MHz/hr

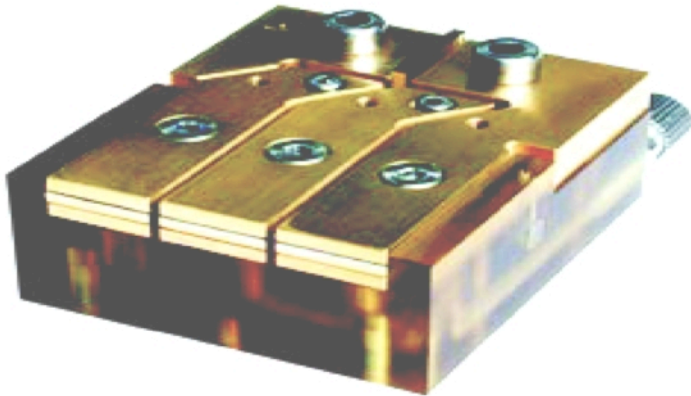


- 1. Study of frequency stability requirements for autonomous airborne applications of the Doppler lidar at the thermal and vibration environment on UAVs;**
- 2. Possibility of utilizing novel conductively cooled high-power diode bars and/or a novel gain module design (Option #1);**
- 3. Power scaling by increasing the repetition rate to 2 - 3 kHz (Option #2);**
- 4. Mechanical ruggedization of the transmitter design.**



Pulse energy scaling: Option #1

*nLight Photonics High-Power
Horizontal Stacked Arrays provide
state-of-the-art power levels in a
compact package*



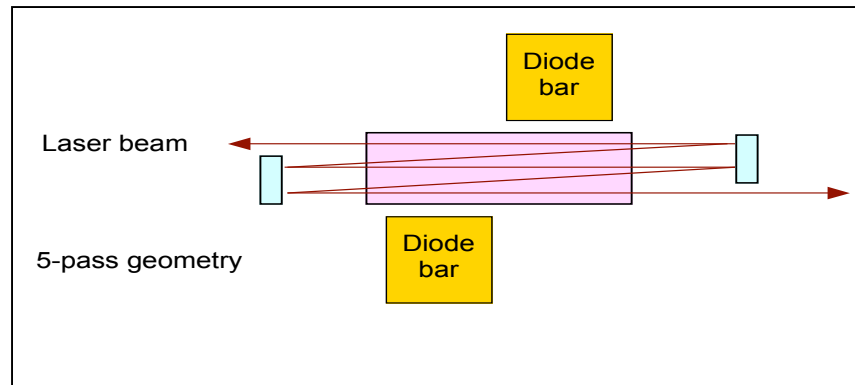
**The new design would allow us to
scale up the oscillator pulse energy
up to ~16 mJ at a 1 kHz repetition rate**

PRODUCT SPECIFICATIONS

Output power, peak	300-watts pre lens 285-watts, post lens
Pulse width and Repition rate	500 microseconds, 1 kHz
Polarization	TM
Center Wavelength, nm	805 +/- 3nm @ 25 degrees C
Spectral Width (FWHM)	</= 3nm
Fast Axis Array Beam Divergence	< 0.5 degrees, FWHM
Slow Axis Array Beam Divergence	</= 10 degrees, FWHM
Beam Characteristics	Collimated, >900um vertical beam width
Operating Temperature	25 degrees Centigrade

**Option #1 will allow us to make
the laser head more compact and
achieve 4 W of average power
at 349 nm at a 1 kHz pulse rate,
with no amplifier**

Average power scaling: Option #2

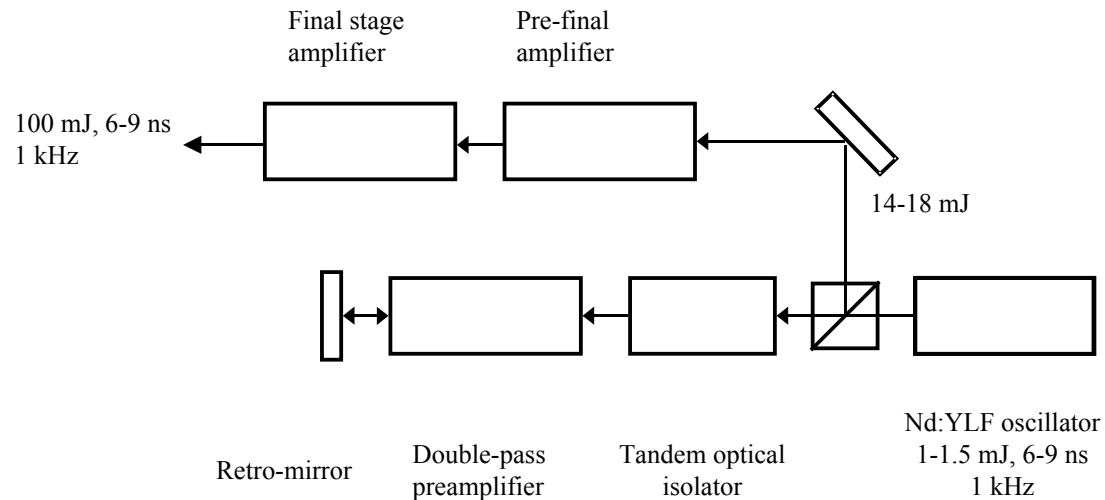


Standard 5-pass Nd:YLF Gain Module geometry;
MOPA system with one amplifier;
No pump diodes with microchannels;
Conduction water cooling;
2 - 3 kHz pulse rate;
2.5 -3 W average power at 349 nm

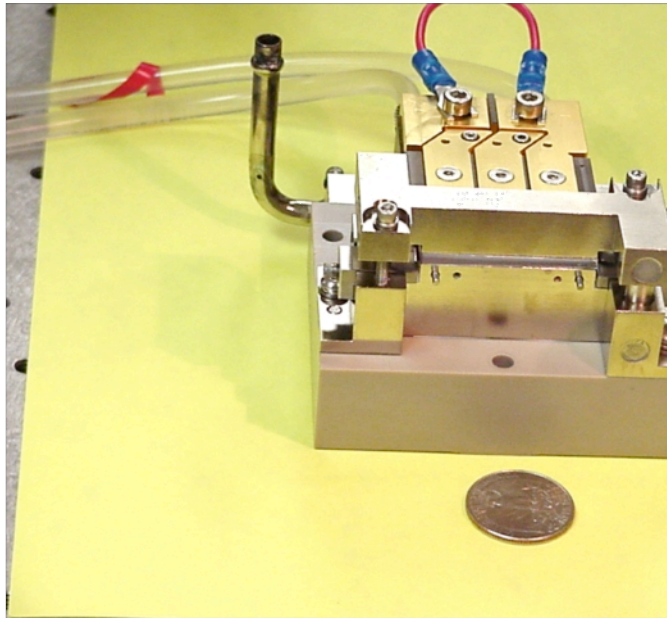


100 W IR source for ozone lidar (in progress)

Required Pump Laser Parameter	Units
Wavelength	1047 nm
Linewidth	<500 MHz SLM (no multimode permitted)
Average Power	100 W combined
Main leg	70 W
Secondary leg ** after OPO isolator	30 W **
Pulse width	6-8 ns (critical not to exceed)
Beam diameter	< 2 mm 1/e ² points
Beam quality	M ² < 1.3 in both axis
Beam shape	Near circular > 90%
Pulse shape	>95 % gaussian , no after pulsing



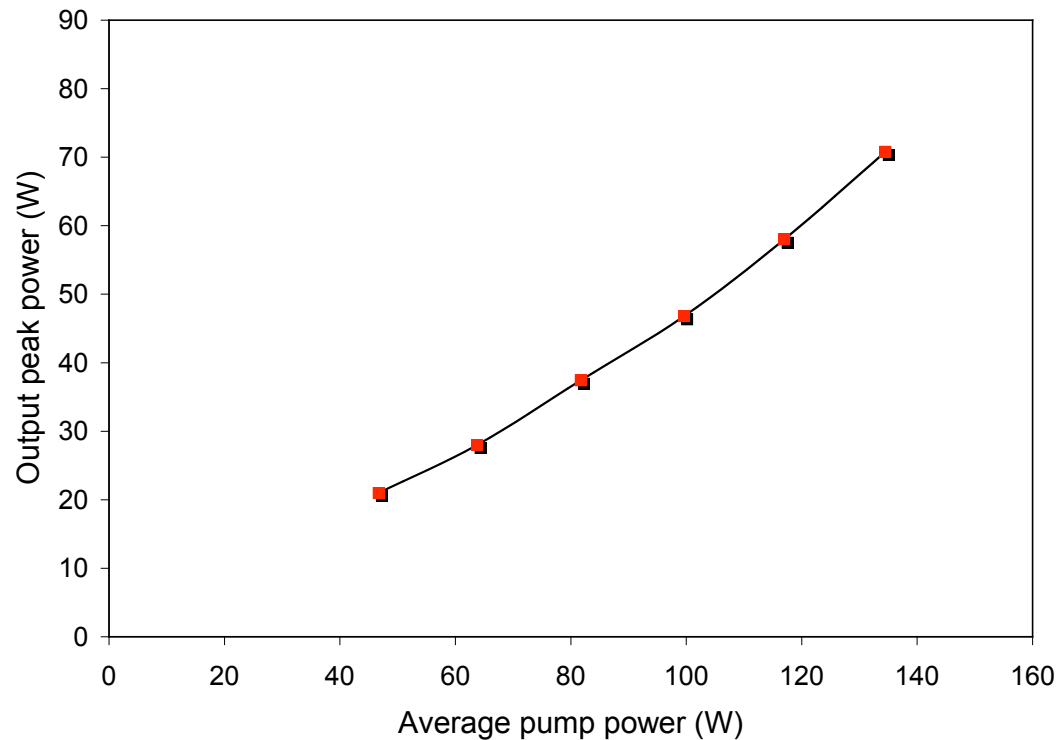
New Three-Pass, Three-Bar Gain Module (GM)



- **Only one cooling block for the array is needed, for the new GM as compared to the two-cooling blocks, diode-offset design. This facilitate fabrication and assembling of a GM.**
- **3-pass design eliminates the possibility of parasitic amplification that may occur in the 5-pass design due to partial overlapping of the HR multipass mirrors.**
- **Use of 0.8%-doped Nd:YLF slab decreases losses due to upconversion that takes place at high pump power in Q-switched operation.**



Performance of new GM in oscillator and amplifier configurations



Oscillator:
~80 W maximum peak
power achieved at a
1 kHz repetition rate,
50% duty cycle

Amplifier
for Q-switched pulses:
55 mJ/pulse output achieved
at 24 mJ/pulse input at a
1 kHz repetition rate,
50% duty cycle



Conclusion: Potential applications

The technology developed is of particular use to the NASA for lidar transmitters. Specifically, the pulsed UV source can be used for wind measurements or Raman probing of the atmosphere based on direct detection of Rayleigh or aerosol-scattered light. Other NASA applications could include space-based aerosol sensing using the laser fundamental and harmonic wavelengths, similar to the LITE mission that flew on the STS.

Much of the Nd:YLF technology we are developing for aircraft-based sensors can be scaled to spaceborne sensors.

For the commercial market, this technology could be used as a low-cost driver for a solid state, pulsed UV source for via drilling, and other precision micro-machining applications.